GOFF DIAGRAM FOR MOIST AIR

It is a fundamental proposition of thermodynamics that *when a fluid flows across a section fixed in space it convects with it an amount of energy equal to its enthalpy as determined by the pressure, temperature, and composition of the fluid at that section.* This fundamental proposition provides the correct procedure for applying the law of conservation of energy to the processes occurring most frequently in air conditioning practice. Thus if moist air is flowing through a duct it carries across any section of the duct energy of amount mh Btu per minute and water of amount mW pounds per minute, if m denotes the weight of dry air crossing the section per minute.

The foregoing considerations suggest the importance of having accurate knowledge regarding the enthalpy of the fluid in question and the desirability of using enthalpy as one of the coordinates in graphical representation. The use of enthalpy h and humidity ratio W as coordinates in the case of moist air is due to Mollier[4]. A convenient modification of the Mollier diagram introduced by Goff and designated Goff Diagram for Moist Air is obtained by taking humidity ratio W as ordinate and reduced enthalpy (h-1000W) as abscissa. A Goff Diagram modified in this way is enclosed in the envelope attached to the inside back cover and an abridgement of the Diagram is shown in Fig. 1.

The Goff Diagram is a constant-pressure chart, the one provided with this book being drawn for standard atmospheric pressure from the data in Table 1. Along the axis of abscissae ($W = 0$, $\mu = 0$) are plotted values of the specific enthalpy of dry air h_a at one-degree intervals of temperature. Values of humidity ratio at saturation W_s plotted against values of reduced enthalpy at saturation (h_s-1000W_s) determine the saturation curve ($\mu = 100$ per cent). Lines of constant temperature connect points on the saturation curve with corresponding points on the dry-air axis and are inclined upward to the right. They are drawn straight in accordance with Equations 3 and 5 because the curvature contributed by the correction term 5a is inappreciable at all temperatures within the range of the chart. The portion of each isotherm lying between the dry-air axis and the saturation curve is divided into 10 equal parts by curves of constant per cent saturation. The per cent saturation of any point below the saturation curve is readily determined by linear interpolation along the isotherm through that point.

Each isotherm breaks at the saturation curve to incline upward to the left into the two-phase region above the saturation curve. The ordinate of a point in this region is the total weight of water in both the vapor phase (moist air) and the condensed phase (liquid or solid) per pound of dry air in both phases. Neglecting the very small amount of dissolved air in the condensed phase, it is the weight of water in both phases per pound of dry air in the vapor phase. The ordinate at the break in the isotherm through the point in question is the weight of water per pound of dry air in the vapor phase. Consequently, the difference between the two ordinates is the weight of condensed phase per pound of dry air in the vapor phase.

It has been stated that the region above the saturation curve is the two-phase region. This is so except in the wedge with apex on the saturation curve at 32 F where three distinct phases, namely, solid, liquid, and vapor coexist. In fact, this wedge separates the liquid-vapor region above the wedge from the solid-vapor region below it. A point inside the wedge divides the horizontal line extending through it from one boundary

to the other into two segments which are in the same ratio as are the weights of solid and liquid. The temperature is 32 F throughout the wedge.

The isotherms in the two-phase regions above the saturation curve have been extended downward to the right into the vapor-phase region below the saturation curve as lines of constant *thermodynamic wet-bulb temperature*. The definition of thermodynamic wet-bulb temperature will be given later.

On the Goff Diagram provided with The 1949 Guide there has been drawn a *protractor* from which can be determined the direction in which the state point of a mixture of water and dry air will be moved *by simultaneous addition of energy and water without addition of dry air*. A particular direction is specified by the numerical value of the *ratio of energy to water added* which ratio is designated as q and called the *specific enthalpy of water added, Btu per pound*. The protractor is useful in locating the *condition line* of a cooling load or heating load problem.

DERIVED PROPERTIES

Thermodynamic Wet-bulb Temperature. For any state of moist air there exists a temperature t^* at which liquid (or solid) water may be evaporated into the air to bring it to saturation at exactly this same temperature. The humidity ratio of the air is increased from a given initial value W to the value W_s^* corresponding to saturation at the temperature t^*; the enthalpy of the air is increased from a given initial value h to the value h_s^* corresponding to saturation at the temperature t^*; the weight of water added per pound of dry air is $W_s^* - W$ and this adds energy of amount $(W_s^* - W)\,h_w^*$, where h_w^* denotes the specific enthalpy of the water as added at the temperature t^*; therefore, if the process is strictly adiabatic;

$$h + (W_s^* - W)h_w^* = h_s^* \qquad (7)$$

The solution of Equation 7 for given values of h and W is called *thermodynamic wet-bulb temperature*.

Example 1. Find the thermodynamic wet-bulb temperature of moist air at 80 F, 50 per cent saturation, atmospheric pressure.

Solution. From the data of Table 1, the enthalpy of the air is $h = 19.221 + 0.50 \times 24.47 = 31.46$ Btu/lb (Equation 5). To a first approximation this is the enthalpy at saturation at the thermodynamic wet-bulb temperature which is therefore approximately 67 F.

At 67 F the humidity ratio at saturation is 0.01424 lb_w/lb_a and the specific enthalpy of liquid water is 35.11 Btu/lb_w. The humidity ratio of the air is $W = 0.50 \times 0.02233 = 0.01117$ lb_w/lb_a (Equation 3). Therefore, to a second approximation, the enthalpy at saturation at the thermodynamic wet-bulb temperature is $h_s^* = 31.46 + (0.01424 - 0.01117) \times 35.11 = 31.57$ Btu/lb_a, Equation 7. Interpolation in Table 1 gives as final answer,

$$t^* = 66.94 \text{ F}$$

The answer can also be read directly on the Goff Diagram at the intersection of the 80 F dry-bulb and 50 per cent saturation lines.

The psychrometer is an instrument consisting of two thermometers one of which has the bulb covered with a suitable wick that has been dipped in liquid water and thoroughly wetted by it. On placing the wet-bulb of the instrument in an air stream, the liquid begins to evaporate from the wick and it is usually assumed that such evaporation brings the air immediately adjacent to the wick to saturation. At first this air may reach saturation at a higher or lower temperature than that of the liquid on the wick; but in a relatively short time the temperature of the liquid will have